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Department of Energy Technology Annual Progress Report 1 January - 31 December 1987

B. Micheelsen and F. List

Risø National Laboratory, DK-4000 Roskilde, Denmark
March 1988

Risø-R-559

DEPARTMENT OF ENERGY TECHNOLOGY
ANNUAL PROGRESS REPORT
1 January - 31 December 1987

Edited by
B. Micheelsen and F. List

Abstract. The general development of the Department of Energy Technology at Risø during 1987 is presented, and the activities within the major subject fields are described in some detail. Lists of staff and publications are included.

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CONTENTS

1. DEVELOPMENT DURING 1987

1.1. The Department of Energy Technology

The Department of Energy Technology has been ever changing - or developing - since it gave up its original objective of nuclear reactor technology research. During 1986 the Section of Reactor Physics was renamed the Section of Process Simulation, because the main effort of the section was now on simulation of dynamic processes. This year, 1987, an organizational change was made at Risø with the purpose of strengthening and combining the work within informatics, cognitive science, and process simulation. As part of that change the staff working on process simulation in the Department of Energy Technology was transferred to the Department of Information Technology, while the reactor physicists stayed in this department. This split up left the environmental modelling group in the former Section of Process Simulation a bit isolated, and a new affiliation for this group was discussed towards the end of 1987.

This annual report includes contributions from the environmental group, while the process simulation group is reporting elsewhere.

During these changes the objectives of the reactor physics work were discussed, and the following was concluded:

1) to maintain reactor physics research, development, service and education, and

2) to organize a working group for "Knowledge Preparedness". This is a group maintaining knowledge on nuclear reactors and nuclear R & D. (This work should not be confused with emergency preparedness, where a large organization is set up for a specific nearby reactor). The working group consists of approximately 15 senior scientists from the reactor physics group, the DR3 staff, the Health Physics Depart-

ment, and the Technical University of Denmark. The members of the working group are expected to work approximately one month per year at this task.

Also other subject fields of the department were scrutinized during the year. Strategy plans for the coming years were created both for the field of combustion R & D and for petroleum-related R & D. This strategy work demanded many meetings and much paper work, and especially the section leaders were given a large extra work load. Both strategy plans gave good moral support for the future work, and also some extra financial support.

One major effort during the year was the dismantling of the first 2 MW circulating fluid bed reactor; following this, an advanced circulating fluid bed system, with an automated control system, steam generator, and coal and straw feeding systems, was designed and constructed. Experiments on the system began late in the year. This work was done for a Danish boiler manufacturer.

Another significant development was that the basin modelling project, where our Reservoir Group cooperated with the Geological Survey of Denmark and the Technical University, was broadened to include two international experts, Dansk Olie- og Gasproduktion A/S (DOPAS), and the universities. This has led to a rather large project, where a 3-dimensional basin model is being used in evaluating the oil-gas potential of three Danish locations. A future commercial cooperation in basin modelling studies for fields outside Denmark is being considered.

1.2. The Reactor Physics Group

The main activites in the Reactor Physics group have been:

- verification calculation for the LEWARD-NOTAM code system
- gamma radiation estimation for the TOKAMAK fusion reactor, NET
- supporting calculations for other departments, mostly in

connection with DR3-utilization, and

- implementation and modification of codes for calculation of aerosol behaviour, mostly within the Nordic AKTI research programme

The LWR fuel assembly code LEWARD has been used for preparing data for the BWR core simulator code NOTAM for a core-follow study of the Quad Cities 1 reactor. The outcome of the study is detailed in section 2.

As part of the EEC Fusion Technology Project calculations have been made of the radiation levels in a TOKAMAK fusion reactor, NET. First, neutron flux distributions in the reactor were determined by means of the Monte Carlo code MCNP2 and used in a burnup code, ACTIVA, for gamma emission calculations. Then, MCNP2 calculations on gamma transport alone were made and, together with a reciprocity argument, used to estimate the gamma radiation level at a selected point outside the reactor.

A large number of calculations with different reactor physics codes have been performed as support for

- DR3 fuel management
- conversion from 93% to 20% enriched fuel in DR3
- silicium irradiation in DR3 for semi-conductor production
- "warm" neutron source in DR3
- fission gas release examinations of highly irradiated specimens of power reactor fuels

The Reactor Physics Group has contributed to the CEC DEMONA Benchmark Exercise (W. Schöck, ed., in press). In this exercise aerosol codes were compared to each other and to an experiment performed at the Battelle model containment in Frankfurt. The Reactor Physics Group contributed to the NEA/CEC Workshop on Water-cooled Reactor Aerosol Code Evaluation and Uncertainty Assessment (to be published). The work in the Nordic AKTI project continues. However, the emphasis has now shifted somewhat from containment aerosols to primary system aerosols. Under contract with the Danish utility group ELSAM the code MARCH-3, a part of the USNRC Source Term Code Package, was implemented.

1.3. Heat Transfer and Combustion

Coal combustion and implementation of measurement technique for combustion and environmental problems have formed the major part of the work during the year. However combustion of biomass, specially straw combustion, seems to become a research subject of increasing importance. The background for this change is the policy adopted by the Danish Goverment to widen the use of domestic fuel in district heating plants.

The 2-MW circulating fluid bed, built and used intensively for experiments during 1986, was dismantled in 1987, and a new advanced circulating fluid bed with steam generator and an automatic control system was built. Because of the great interest in straw combustion, systems for handling and feeding straw were added in order to investigate the problems in straw combustion which are related to the low melting point of the ash and the chloride content of the straw. This modification was finished late in 1987. The work was done in close cooperation with Aalborg Boilers A/S.

The laboratory for fundamental combustion research is still in a start-up phase. The test facility for single-particle combustion was modified in order to obtain more well-defined measurement conditions. Work on fuel reactivity and flash pyrolysis has been initiated. The specifications of a laser system for measuring particle sizes have been given.

A large 2-MW furnace that burns pulverized coal or gas has been designed and the shake-down experiments are expected to take place during the summer of 1988.

In the theoretical field the work on a 3-dimensional turbulent particle/gas flow model has been continued. Separate gas and particle flow models are in the main part finished; the combustion part is not yet ready.

An experimental and theoretical study of interface friction in two-phase stratified water-air flow (simulating oil-gas flow) has been performed together with the consulting company LICconsult. The experimental work was done at the Technical University of Denmark.

The temperature calibration laboratory has calibrated thermometers for Risø and other customers during the year. The amount of work for customers outside of Risø has increased significantly compared to last year.

1.4. Reservoir Group

The work may be described under the three headings: Reservoir Technology, Basin Models and Heat Storage.

The development of the 3-dimensional, fully compositional, double permeability reservoir simulator, COSI, has been continued and the compositional routines have been included. A number of compositional test cases have been calculated and reported. Improved input and output facilities have been developed.

The simulation of fractured reservoirs has been given special emphasis. Experiments in laboratory scale with sand packs performed at the Technical University of Denmark have been compared with calculations. The problem of applying the results to the dual permeability simulator, with grid blocks containing many matrix blocks and fractures has been addressed in collaboration with the consulting firm Dancomp Aps. Further experiments on fractured cores are planned at the Geological Survey of Denmark.

A computer-assisted method for determining relative permeabilities from transient experiments was under development in collaboration with the Geological Survey and the Technical University.

The work on basin modelling has been continued with a view to increased exploration efficiency.

The 1-dimensional basin simulator that has been developed previously has been modified for easier use. The simulator is in use at the Geological Survey.

A Danish basin modelling group has been established as a collaboration between the internationally recognized experts, Arif M. Yükler and Gordon S. Speers and a number of Danish parties: the Geological Survey, Dansk Olie- og Gasproduktion A/S, Risø National Laboratory, the Technical University, and the universities of Copenhagen and Aarhus.

In 1987 the group has been working on basin studies for a number of Danish areas using the 3-dimensional basin simulator developed by A. M. Yükler. This work will be finished in 1988.

A more permanent group for basin studies is planned to include A. M. Yükler, Gordon S. Speers, the Geological Survey, Dansk Olie- og Naturgas A/S and Risø. This group is set up to work also outside the Danish area.

Research and development work for further improvement of the Yükler-model was also started in 1987.

Furthermore the Reservoir Group has continued its participation in the Danish aquifer heat storage project.

1.5. Danish Reactor DR 1

The reactor has been used for educational purposes only. A number of students from technical universities in Denmark and Sweden have carried out experiments at the reactor over periods of 2-8 days, and 55 high school classes have carried out one-day experiments.

The following experiments were performed:

- Estimation of control rod position when the reactor becomes critical.
- Determination of reactor constants, power coefficients, temperature coefficient and bubble coefficient.
- Determination of neutron flux distribution and absolute thermal flux.
- Neutron activation analysis.
- Gamma spectroscopy with scintillation detector.
- Measurements of total neutron cross sections of different materials.
- Neutron radiography.
- Experiments concerning health physics and decontamination.

In order to be able to improve and continue the courses at the present level, funding has been applied for and was granted by the Danish Egmont Fund.

1.6. The Environmental Modelling Group

During 1987 the efforts have been focussed on two main issues:

1) improving the already existing model of soil chemistry, and
2) developing a forest model.

Concerning the soil chemistry model a function to describe the carbon dioxide content in the ground during a given year has been introduced. When the pH is above 4 a knowledge of the CO_2-concentration in the ground is important in order to estimate the pH-value reliably. Furthermore, changes have been made in the part of the model that describes the absorption of heavy metals (exemplified by cadmium) by the soil, and the temperature dependencies in certain chemical processes have been introduced.

The work on the forest model has been concentrated on two points:

a) processes occurring in the canopy. These are important for predicting the composition of the water that reaches the ground.

b) litter fall's decomposition and release of nitrogen.

2. ACTIVITIES OF THE DEPARTMENT

2.1. Comparison of LEWARD/NOTAM Results with Measurements on the Quad Cities 1 Reactor

The LWR fuel assembly code LEWARD (HØJERUP, 1987) has been used for producing cross section tables to the core simulator NOTAM (SCHOUGAARD, 1979).

A core follow study was then performed with NOTAM for the first fuel cycle of the Quad Cities Reactor. This reactor is of General Electric design, and a very detailed experimental program has been conducted for the two first fuel cycles (General Electric, 1976), yielding a unique collection of data for code verifications.

The initial core had the following three fuel assembly types:

- Assemblies without gadolinium
- Assemblies with 2 Gd-poisoned fuel pins
- Assemblies with 3 Gd-poisoned fuel pins

2-group cross section tables for these 3 fuel types were produced with LEWARD as function of burn-up and void content. All calculations were repeated with a control rod inserted. The core simulator program NOTAM interpolates in the cross-section tables for the fuel and calculates the steady-state combination of temperature- and void distribution that applies to a given core layout, control rod pattern, and burn-up distribution.

The deviation of the calculated k_{eff} from unity is one measure of the quality of the calculations. This is shown in Fig. 1.

The agreement is considered satisfactory except at the end of the cycle, where presumably errors from control rod treatment are responsible for the deviations.

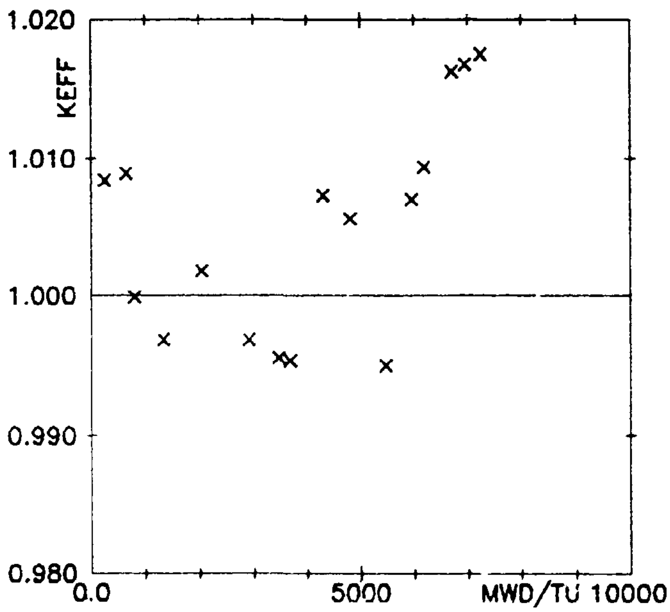

Fig. 1. Calculated K_{eff} values for cycle 1.

A far more sensitive measure is the detailed 3-dimensional power distribution as given by the readings from 41 travelling incore probes (TIP). The TIP's are placed in 41 positions in the core in such a way that all sets of 4 fuel assemblies are covered (due to a quarter core symmetry). Axially the TIP's measure at 24 elevations along the assemblies.

In Fig. 2 four examples of TIP measurements together with calculated curves are shown. They form a very small part of the total number of possible comparisons. They refer to the start of reactor operation (247 MWD/tU), and the agreement is reasonably good. At larger burn-ups the agreement gets poorer as would be expected.

A number of areas, where improvements can and ought to be done, have been identified:

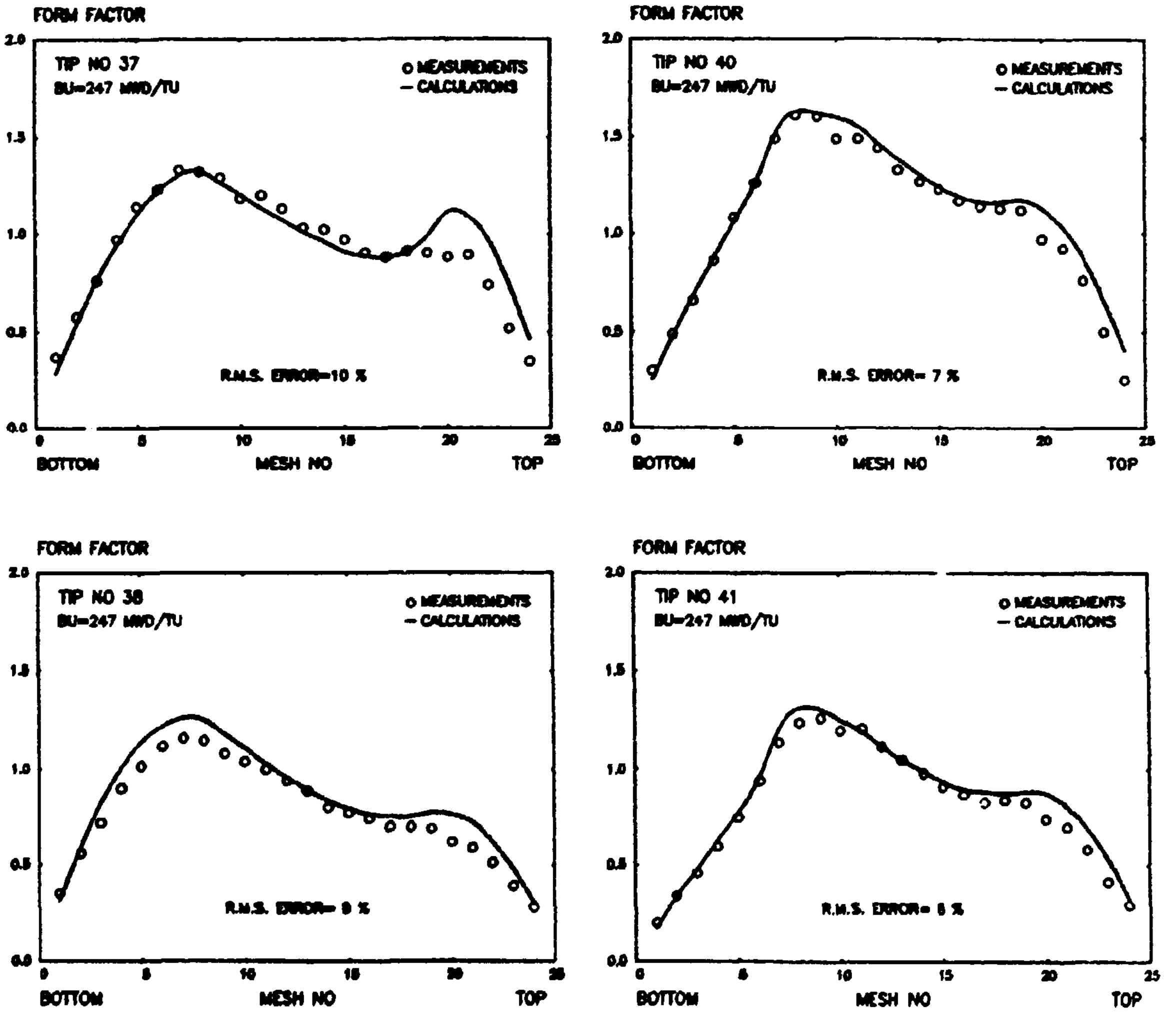

Fig. 2. Measured and calculated power profiles.

- The numbers we compare with the TIP-readings are simple averages from four neighbouring assemblies. A better combination procedure than simple averaging should be devised.

- Voids outside the fuel boxes are assumed to be zero. This assumption is invalid in some core positions, and means to cope with this should be included.

- Control rod histories (that is, for how long a time has a given fuel assembly existed with a control rod inserted) are not considered. This is obviously a serious error, but remedies against it may be difficult to find.

C.F. Højerup and E. Nonbøl

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HØJERUP, C.F. (1987). LEWARD, An LWR Assembly Programme. Risø-I-293. 19 p. (Also appearing in: VTT Symposium 79, 3. Nordic Reactor Physics Symposia. Status of Reactor Calculation in the Nordic Countries, Helsinki, 31 March - 1 April 1987).

SCHOUGAARD, B.F. (1979). A short Description of the Programme NOTAM. 25 p.

General Electric Co. (1976). Core Design and Operating Data for Cycle 1 and 2 of Quad Cities 1. EPRI NP-240. 300 p.

2.2. Energy Distribution in a "hot" Neutron Source in DR 3

In the Department of Physics at Risø a project has been initiated with the purpose of developing a so-called "hot" neutron source in the reactor DR 3. This source should provide neutrons with energies in the range 300-80 meV corresponding to de Broglie wavelengths of 0.5 - 1.0 Å. Such wavelengths enable the experimenters to study crystalline systems demanding a very high number of reflections.

The source itself consists of a thermally insulated graphite block positioned in the centre of one of the horizontal test tubes in the reactor. The heating of the graphite is provided by gamma radiation from the reactor.

The energy distribution of neutrons in the graphite block has been calculated at different temperatures. The calculations have been made with the 2-dimensional neutron diffusion code DIFF2D, developed several years ago.

The input to the code has been obtained from the 3-dimensional calculational model DR3/SIM that provides the neutron flux in the horizontal test tube filled with helium (NONBØL, 1985). The DIFF2D code, applying the cylindrical option, has then been adjusted to the solution from DR3/SIM and a detailed calculation in 30 energy groups has been made.

In Fig. 3 a comparison between measurements and calculations of the neutron flux spectra in a H_2O scatter at 283 K (thermal neutron source) is shown positioned in the centre of the test tube. This good agreement has served as a kind of verification of the model of calculation applied.

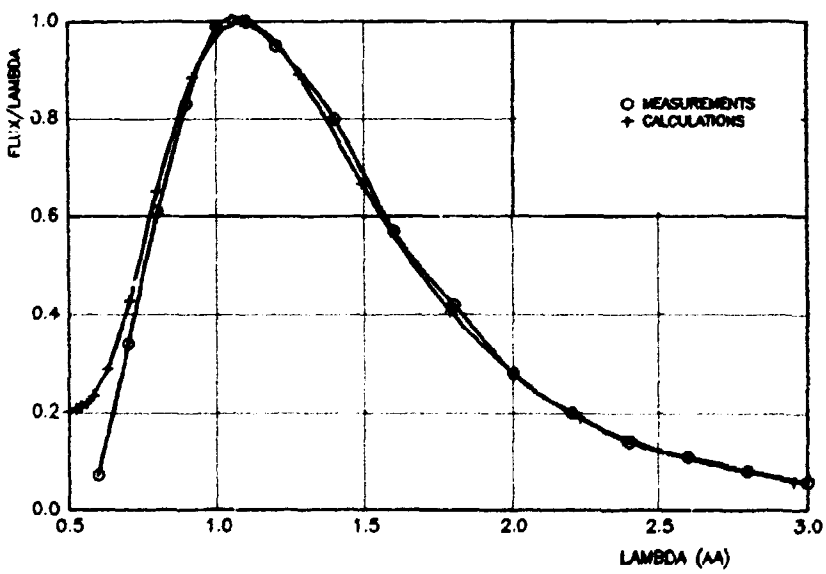


Fig. 3. Neutron flux spectra in H_2O scatter at 283 K

Fig. 4 shows the neutron flux spectra in a graphite block at different temperatures. In the figure the spectra from the thermal neutron source is also shown. A comparison between this curve and the curve for graphite at 1500 K shows a gain in the flux of about 6.0 at a wavelength of 0.5 Å.

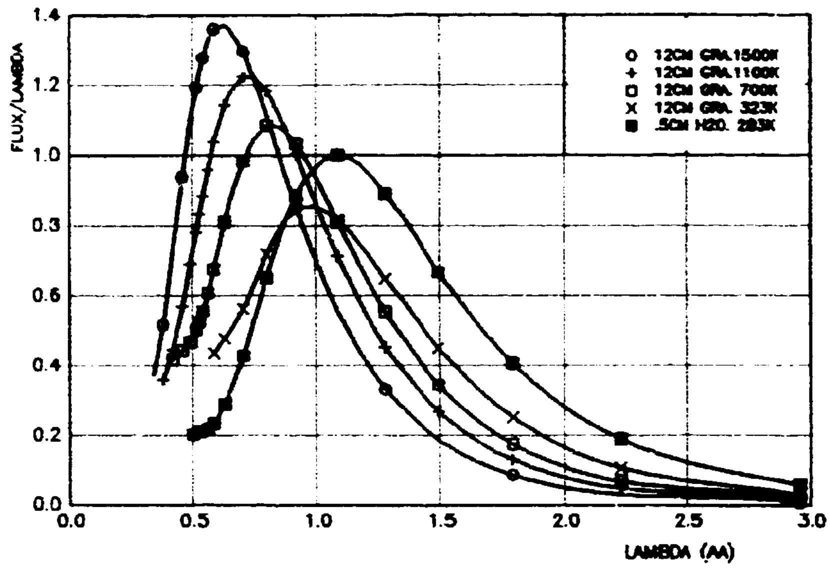


Fig. 4. Neutron flux spectra in hot source scatter at different temperatures.

The reactor physics calculations of the proposed design to the "hot" neutron source thus has shown that a considerable increase in the flux can be achieved for wavelengths of about 0.5-1.0 Å.

E. Nonbøl

REFERENCE

NONBØL, E. (1985). Development of a Model of the Danish Research Reactor DR3. Risø-M-2550. 20 pp.

2.3. The Temperature Calibration Laboratory

The Temperature Calibration Laboratory was accredited in 1978 by the Danish National Testing Board to carry out certified calibrations of temperature sensors in the -150°C to 1100°C range according to the International Practical Temperature Scale IPTS-68. In 1986 the accreditation was extended to cover the calibration of electrical resistances in the range 0-1100 Ω and d.c. voltages in the range 0 - 1.1 V. The standard thermometers, the standard resisters, and the voltage standard cells in the Laboratory are traceable to the National Physical Laboratory, England.

The number of calibrations for external customers has increased steadily during the years. In 1987 the Laboratory had performed 186 jobs for external customers and 6 for other Risø departments. In all 842 thermometers ranging from liquid-in-glass models to advanced digital types and 9 thermostats have been calibrated during the year. The calibrations have been made in the temperature range from -150°C to 1100°C which covers the whole range accredited.

A series of temperature measurements has been performed for external customers on site.

At an automobile factory in Sweden the temperature distribution has been measured in a wind-tunnel for a full-size climate test of automobiles at arctic and tropic conditions.

The temperature distributions in a number of laboratory furnaces at different working conditions have been determined for a Danish medicine manufacturer.

Finally, a series of temperature measurements has been made in a waste incineration plant using a specially developed suction pyrometer.

F. Andersen/N.E. Kaiser

2.4. Fundamental Combustion Research

A system for the study of the combustion of single coal particles was set up in the laboratory, and is now being developed further. During the burning process, the coal particles can be studied through quartz windows with laser and TV-camera systems. Particle flow rates can be monitored and gas composition and temperature can be controlled. To support experimental results a model describing coal particle combustion is being developed.

Flash pyrolysis experiments on coal particles are studied in collaboration with the Chemistry Department. The aim is to obtain information on particle history, volatile-, nitrogen-, sulfur- and char reactivity. This work is a Nordic cooperative study, where the results are co-ordinated and intercalibrated.

L. Holst Sørensen

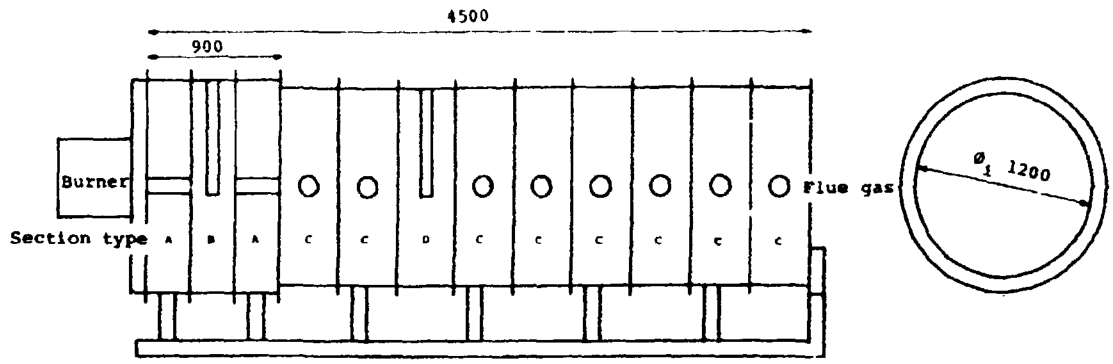
2.5. Experimental Investigation of Pulverized Coal-burners

In the process of construction of pulverized coal burners with a small emission of NO_x, it is important to have a better knowledge of the processes in the near burner field, and in this project an experimental investigation of the flow field and the combustion characteristics in the near burner field will be examined.

The experimental facilities were designed during 1987, and an experimental furnace will be built in spring 1988. It will have a single burner and operate at a maximum power of 2 MW. It will be possible to conduct investigations of local conditions in the furnace and to test flue gas cleaning processes.

Design of Furnace

The furnace is built of circular calorimetric sections, the first three of which are refractory lined. All sections have measuring ports to make local measurements possible throughout the furnace (Fig. 5).



Furnace section type		A	B	C	D
Length	mm	300	300	400	400
Refractory lined	mm	50	50	none	none
Measuring ports		1-slit 100x300 1-ø100	1-slit 180°x90	2-ø150	1-slit 180°x90

Fig. 5. 2-MW pulverized coal-fired furnace

The facility will be instrumented to the extent where it will be possible to measure all important parameters. A computer will log data from the experiments. The following parameters will be measured.

- Primary and secondary air flow
- Coal flow
- Power from each furnace section
- Surface temperatures

Local measurements in the furnace will be made with the following water-cooled probes:

- Suction pyrometer
- Radiation radiometer
- Gas and solid sampling probe

P. Arendt Jensen

2.6. Testing and Verifying of Laser Measurements in Furnaces

In the spring of 1987 a staff member was stationed at Sandia National Laboratory in USA. During that period the influence of the envelope flame combustion of a droplet on particle sizer system performance was examined.

Work to test laser-based measuring methods in laboratory furnaces has been started at Risø. Primarily velocities of burning coal particles in a drop tube furnace have been measured by a laser doppler anemometer (LDA). Free fall velocities of a wide range of sized fractions of AlO_2 particles in still standing air have been correlated with a particle size analysis using computer image processing.

The particle size distribution is a very important factor when evaluating the results and the accuracy of LDA measurements. Particle sizing methods have been studied, and a laser system was selected for velocity, size and concentration measurements on a 2-MW coal-fired furnace.

S. Clausen

2.7. Interface Friction Factor in Two-phase Flow

A combined experimental and theoretical study of the interface friction in two-phase stratified flow has been carried out as a joint project between Risø National Laboratory, LICconsult Consulting Engineers Ltd. and the Institute of Hydrodynamics and Hydraulic Engineering at the Technical University of Denmark.

The test rig is located at the Technical University. The rig has been equipped with measuring instruments and a computerized data logging system by Risø National Laboratory. The experiments have been run mainly by the Risø staff. The theoretical part of the project including the final treatment of the experimental results has been made by LICconsult.

The rig is about 50 m long including a test section of 36 m with an inner diameter of 90 mm. The test section is partly made of transparent tubes, which make it possible to determine the flow regime visually.

All experiments have been performed with air/water mixtures at horizontal or near horizontal flow. The inclination of the test section ranged from 0.5° upwards to 1.0° downwards. In total more than 400 combinations of waterflow, airflow and inclination have been investigated.

The project was funded by the Danish Ministry of Energy and will be reported in KAISER AND IVERSEN (1988).

N.E. Kaiser

2.8. Computer Modelling of Steady Three-dimensional Turbulent Gas/Particle Flows

Gas/particle flows are found in many industrial applications such as cyclone separators, pneumatic transport of powder, and droplet combustion systems. The aim of the present work is to model the flow and combustion of coal particles with special reference to conventional furnaces for pulverized coal combustion.

Three main parts of the model can be identified. First the turbulent flow of the gas and particles has to be determined. The second part models the devolatilization and combustion of volatiles and the combustion of the char residue. Finally, the thermal radiative heat flux between the gas, particles and walls of the furnace has to be modelled.

The project is done in cooperation with the Laboratory for Heating and Air Conditioning at the Technical University of Denmark. The equations for the 3-D turbulent gas flow are solved numerically with a finite-element technique; an extended k-ε turbulence model that takes swirling- and recirculating flows into account has been implemented. The particle motion is computed by numerical integration of Newton's second law for single particles. The gas particle momentum interaction is modelled as aerodynamics drag, the gas velocity taken as the mean value from the gas flow programme with a random turbulent fluctuation superimposed.

Simulations for inert particles in turbulent flow have been performed, while the reactive part of gas/particle flow as well as radiation has not yet been implemented.

E. Gjernes

2.9. Basin Modelling

In 1987 the work continued on the 1-dimensional basin model developed at Risø. The work was funded by the Danish Energy Ministry. The model is used in exploring for oil and gas. It describes the development of sedimentary basins concerning sedimentation, formation temperature, maturity, as well as oil and gas generation in source rocks. The computer code has been restructured to make it more user friendly. The model is now in use at the Geological Survey of Denmark (DGU) and at Dansk Olie- & Gasproduktion A/S (DOPAS).

Calculation of burial history and formation history in the 1D-model is based on analytical equations. It is assumed that the porosity exponentially decreases with depth (for each formation) and that the heat conductivity is a function of porosity and quartz content. Some of the equations are so simple that the sedimentation history and the heating of the formation can be calculated with a hand calculator. An example of a computed burial history for sedimentary layers is given in Fig. 6. Compaction of the sediments has been taken into account. Calculated source rock maturity values in terms of vitrinite reflectance versus time are shown in Fig. 7. The amount of hydrocarbon material generated in a potential source rock is seen in Fig. 8. The oil degrades with time into gas.

The cooperation with DGU resulted in the development of a 3D-basin model which uses the 1D-model in a network of points. The model was tested on an area in North Jutland. This work was done mainly by DGU.

During the year contacts were established between the Danish basin modelling group and the two internationally recognized experts on oil exploration: Arif M. Yükler and Gordon S. Speers. Yükler has developed the only 3D-basin model in the world, which describes not only generation of hydrocarbons in source rocks, but also the migration and accumulation of hydrocarbons. This is an extension relative to our own 3D-model. It was therefore decided to buy the model. The purchase was funded by the Danish Energy Ministry, DGU, DOPAS and Risø.

At the same time a group was established including Speers, Yükler, and scientists from the University of Aarhus, the University of Copenhagen, DGU, DOPAS, and Risø. The group has reported the results of a 1D-basin study of the southern part of Denmark. Further, a study of the Central Trough (North Sea) has been initiated. Parts of these studies will be available

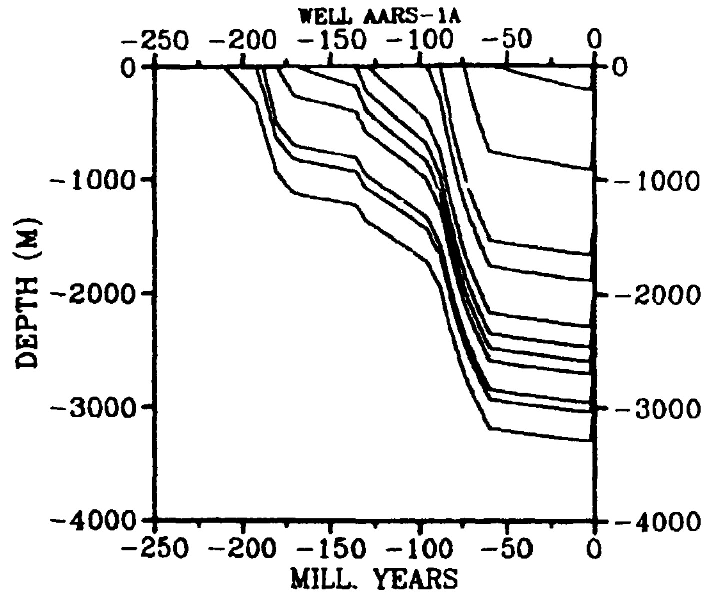


Fig. 6. Sedimentation history for a Danish well

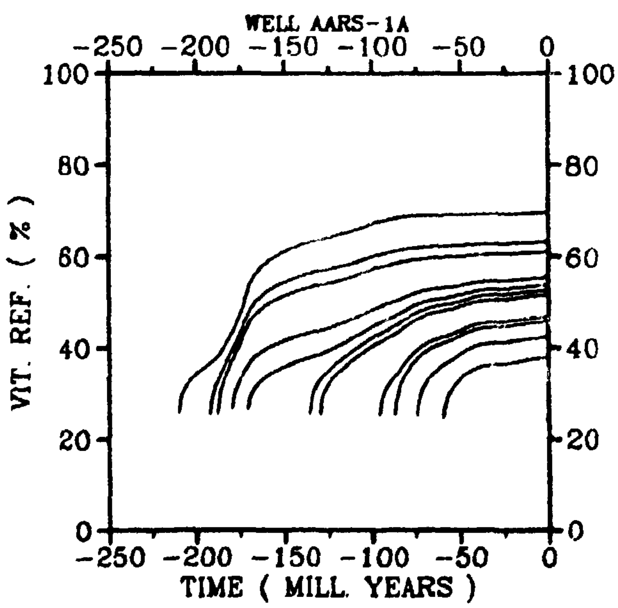


Fig. 7. Maturation history for organic matter

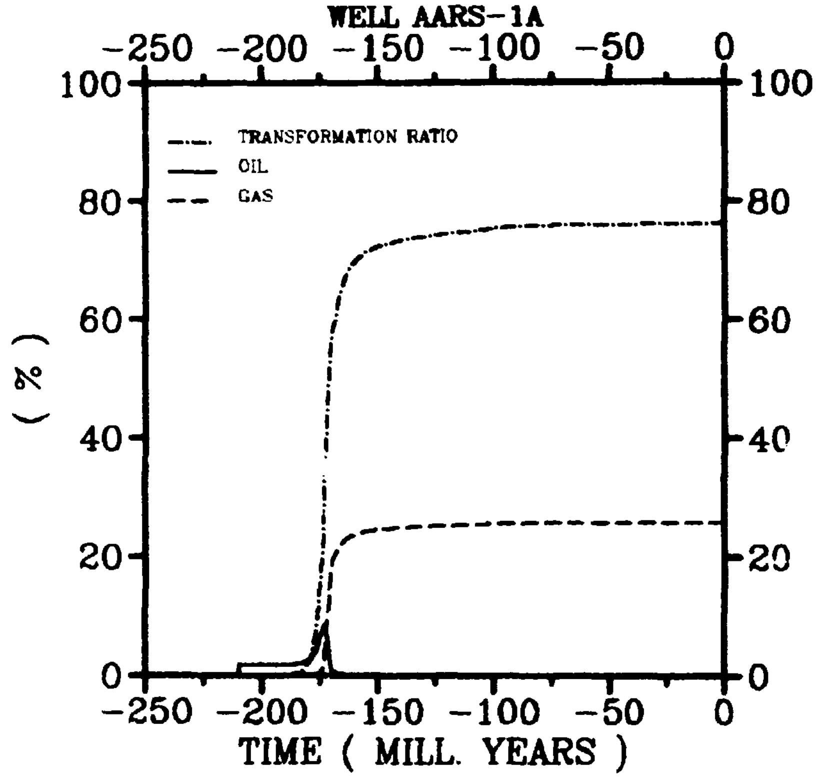


Fig. 8. Oil and gas generation from organic matter through time for a potential source rock. The generation is in per cent of the initial amount of total available organic matter. The transformation ratio is the ratio of transformation of the pyrolyzable amount of organic matter

for sale to the oil companies. Risø contributed to these studies with mapping of subsurface temperatures (in cooperation with Aarhus University) and with mapping of formation pressures.

In 1987 a contract for further cooperation between the two consultants, DGU, DOPAS, and Risø was negotiated. This new group will offer their expertise in basin modelling to the oil companies.

P. Klint Jensen

2.10. Simulation of Oil Displacement Experiments

Basic flow experiments combined with numerical simulation are important for understanding multiphase flow phenomena in porous media. In particular, boundary effects are interesting in connection with flow in fractured reservoirs as well as in many laboratory experiments.

Investigations in this area are performed in collaboration with the Laboratory for Energetics at the Technical University of Denmark, where the laboratory work is done. Furthermore, the collaboration also involves the Geological Survey of Denmark.

Experiments concerning flow in fractured reservoirs are performed in a plexiglass box, 12 x 12 x 3.5 cm, packed with fine and coarse glass beads, representing a matrix and an adjoining vertical fracture, respectively.

The contour plot in Fig. 9 shows a water saturation distribution obtained by a calculation simulating an experiment in this box. Water injected through the bottom of the fracture is imbibed by the matrix, while the displaced oil leaves the box through the top of the fracture. Extremely small grid cells were required in the calculation to obtain a proper simulation of the saturation jump across the interface.

The simulated results compare fairly well with measured oil recovery versus time and with saturation distributions measured by means of an array of resistivity probes. While the purpose of the experiments is to verify the calculation models, the simulations on the other hand were of great value in selecting a suitable material (paper tissue instead of plastic net) to separate the two media without introducing a flow barrier.

The objective of the work is to improve the models for the phase exchange between fracture and matrix in dual-porosity reservoir simulators, where many fractures and matrix blocks are lumped together in each grid block. In order to be sufficiently versatile such models must apply to a wide range of rock and fluid data, wettability properties, matrix block sizes, etc., which require extensive parametric studies. Such studies including a literature survey are initiated, although their scope goes far beyond the limits of the present project.

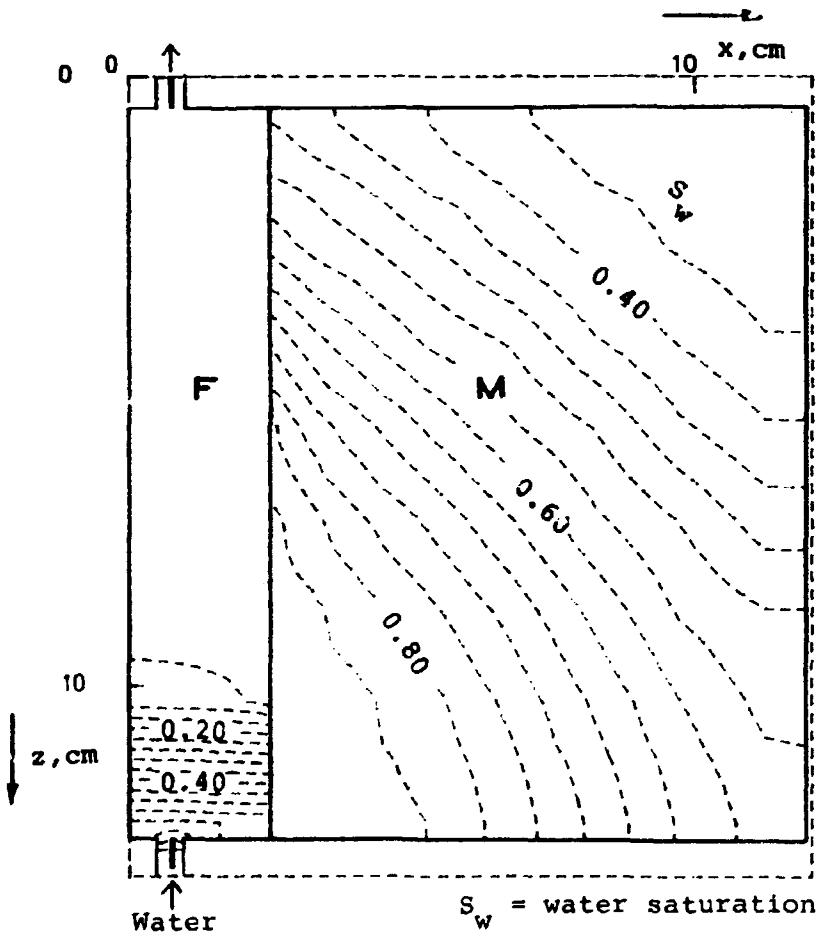


Fig. 9. Simulation of oil displacement from a matrix (M) by imbibition of water rising from the bottom of a fracture (F).

The basic data for the above mentioned simulations had to be established by separate experiments. The relative permeabilities of sand (later replaced by glass beads) to oil and water were measured by conventional steady-state techniques in a vertical plexiglass cylinder (shown in horizontal position in Fig. 10).

The determination of relative permeabilities versus saturation relies on the assumption that the saturations and the pressure gradients are approximately constant over the test section. In order to be able to control the influence of end effects a series of simulations ware performed to analyze the influence of various parameters (described in THOMSEN (1987)).

At the outlet end, the wetting phase (water) is piled up over a certain exit length due to capillary retention at the exit face. In the simulation results presented in Fig. 11 the total flow rate is the same for all four cases, while the water-oil ratio is varied to establish different saturations. It is seen that the exit length (i.e. the length over which the water saturation S_w is increasing) increases with decreasing water-oil ratio. In these one-dimensional cases the inlet effects are ignored.

At the inlet end the two fluids are distributed more or less uniformly. The non-uniformities are evened out by capillary forces over a certain entrance length. These effects are simulated in two-dimensional x-z geometry (replacing the cylinder in Fig. 10 with a slab). The saturation distribution shown in Fig. 12 is obtained in the worst possible case, where the inlet mixer is stopped and the water and oil happen to distribute themselves so as to enter the sand in either side of the inlet chamber. In this case the entrance length exceeds the length of the whole sand pack.

It was further found that while the exit length decreases, the entrance length increases with increasing flow-rate, which stresses the importance of mixing.

The experience gained from these steady-state experiments is being utilized in another project aimed at computer-assisted measurement of relative permeability by the unsteady-state method. It is expected that the use of a combination of simulation and regression techniques will lead to a considerable improvement over the conventional Welge technique. The advantage of unsteady-state methods is their superiority in speed

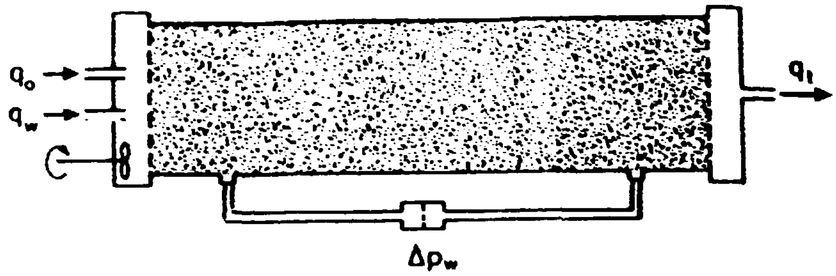


Fig. 10. Relative permeability measurement in sand pack by steady-state method

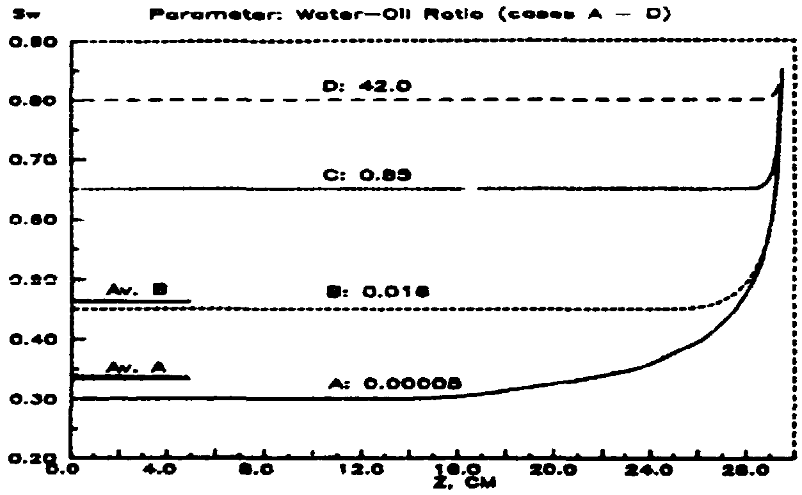


Fig. 11. Simulated water saturation (S_w) distributions showing the influence of water-oil ratio (q_w/q_o) on exit length

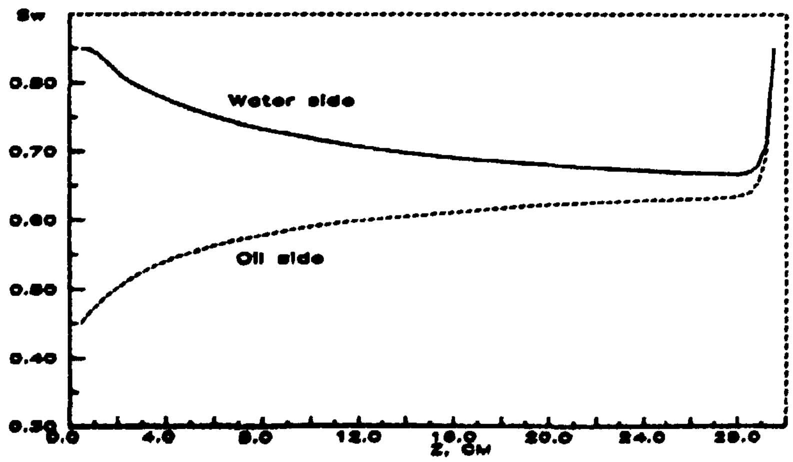


Fig. 12. Two-dimensional simulation of case C with inlet effects, assuming the worst possible inlet distribution of oil and water

relative to steady-state methods, for which the analysis of a single core may take on the order of a month.

K. L. Thomsen

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2.11. Modelling Nitrogen in a Forest Floor

When building up a model for a forest, one of the many important factors one has to consider is the amount of litter on the forest floor and its concentration of various nutrients and ions.

When organic material such as leaves, needles and branches fall to the ground it will immediately start to decompose.

There are basic differences between conifers and deciduous forests, and the contents of nitrogen (highest in deciduous forests) and lignin (highest in coniferous forests) are important for the decomposition process. Due to these differences the decomposition rates of litter from coniferous and deciduous forests are different.

The decomposition consists of three phases:
leaching, accumulation, and release (Fig. 13).

Leaching: Part of the litter consists of soluble material. During this phase the concentration of nitrogen will remain constant. This means that the dry material leaches in an amount which is proportional to that of nitrogen. Generally the higher the content of nitrogen, the faster the decomposition will take place.

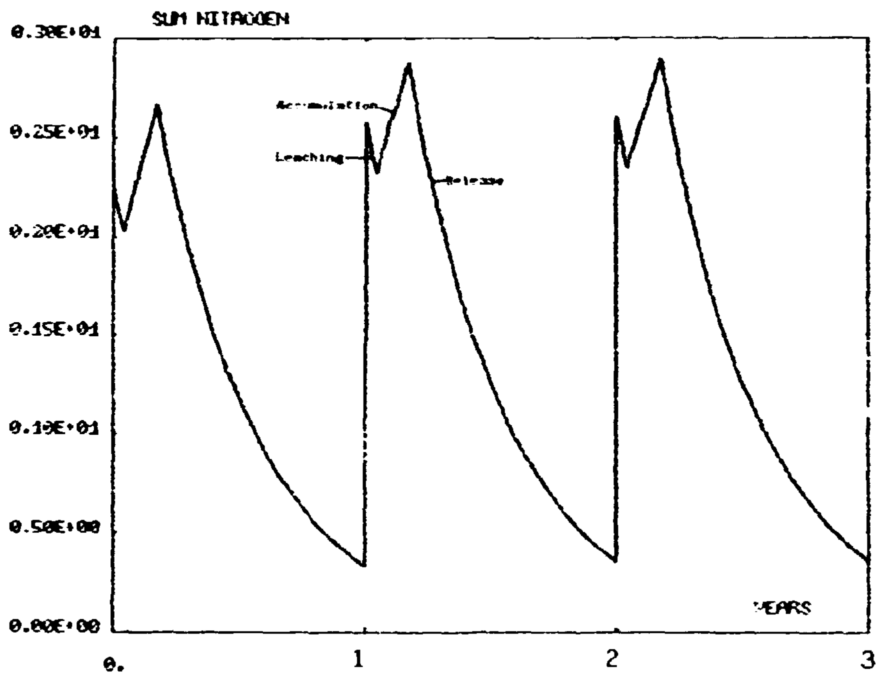

Fig. 13. The three phases of decomposition.
$T_{1/2}$ = 100 days (small).

For this reason leaching is larger for deciduous forests than for coniferous. Another factor that determines the leached amounts is the moisture, as it takes water to dissolve the components.

Accumulation: During the accumulation phase the concentration of nitrogen in the litter rises. The amount of dry material declines and nitrogen is accumulated from

1) Atmospheric precipitation (NO_x)
2) N_2-fixation
3) Dead animals and insects
4) Absorption from old layers of litter

Generally speaking accumulation takes place only if the concentration of nitrogen in the litter is less than 1.4% (Scots pine), and it only accumulates until this concentration (the critical N-concentration) is reached. This means that accumulation normally only takes place in coniferous forests.

Release: The final release starts when the nitrogen concentration has reached a critical level. This level varies from one species to another. (For example, the critical concentration for some pine varies between 0.74 - 1.40%).

It is possible to describe the decomposition kinetics by an exponential expression $C(t) = C_0e^{-kt}$, where $k(\text{year}^{-1})$ is the leaf litter decomposition constant. Due to the relatively high content of lignin, k is small for coniferous trees and larger for deciduous trees; thus $T_{1/2}$ becomes large for coniferous trees. This means that litter will accumulate on the forest floor and decompose only slowly to release its nutrients, whereas a deciduous forest will have a much more rapid circulation.

H. Christiansen

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The general development of the Department of Energy Technology at Risø during 1987 is presented, and the activities within the major subject fields are described in some detail. Lists of staff and publications are included.

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